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The transportation infrastructure and the evolution of street network in Glasgow City Centre

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ABSTRACT

Glasgow had experienced industrial development and rapid population increase in the 19th century. After a century, the city had faced a severe economic decay, population loss and social depression due to the de-industrialization of 1950s. The large-scale regeneration projects of 1960s -including the mass housing and transportation networks have not only reshaped the urban space but also have created new social and spatial issues.

In this study, we aim to analyse the role of transportation infrastructure in defining, shaping, and transforming urban form in Glasgow city centre. In order to deeply understand the urban transformation in the area we first examine the historic evolution of spatial development in Glasgow City Centre through the historic maps since 1860. Then we attempt to analyse the street layout before and after the construction of M8 Motorway in 1965. By doing so, we aim to put forward and discuss the evolution of urban form in relation to the channels of movement/mass transportation investments in Glasgow.

KEYWORDS

Transportation infrastructure, street network, spatio-temporal evolution, space syntax, Glasgow

1 INTRODUCTION

Street networks and urban forms are strongly connected, and both impact each other mutually (Ibrahim & Alattar, 2017). As mentioned by Lynch (1960) streets are one of the main elements of city image. Although the buildings tend to change more due to recline, the streets are more durable elements of the cities and they are fundamental to spatial organization due to their role in connecting people, goods, and urban areas to each other (Strano, et al., 2012; Wang, et al., 2018).

As mentioned by Porta et al., (2014) the major street networks serve as the commercial and service backbone of cities, providing connection from local to regional. And although the street networks tend to sustain longer, the large-scale regeneration, infrastructure and transportation projects cause massive change on urban form.

Glasgow, the biggest city of Scotland with over 600.000 population, had been the most populated urban area in Britain during the nineteenth century. The existing street network has started to appear in 1100s with the first settlements around the Cathedral and the city thrived as a market town due to its convenient location between Highland, Lowland Scotland, and Edinburgh. Glasgow's urban form mainly remained same since the 18th century; however, the redevelopment projects and infrastructure investments since 1960s have reshaped the urban space. Although the grid pattern in the city centre retains its overall layout for more than three centuries, the transportation infrastructure has changed the street layout at the edges of the motorway.

This paper selected Glasgow city centre as the study area and it aims to see the spatial effects of large-scale transportation investments in the area. The study aims to show,

- What drives and affects the evolution of the street network in Glasgow city center since the 19th century?
- What are main drivers/mechanisms of the street network evolution in Glasgow?

2 THEORY

How and why a city works "can only be understood in terms of its evolution over time" (Checkland 1964). In order to understand how urban space formed through time, the economic activities, population movements and the planning decisions should be considered together in relation to each other. In this study we aim to discuss spatial, demographic, economic and policy layers in different historical periods to see how the urban space evolved over time, what are the main trigger of change, and how the planning implementations have shaped the urban space through the years. To do so, first with help of literature review we aim to briefly summarise the notions of space and society, how they modify and configure each other. Then we start to decipher the historical evolution of urban form by analysing historical maps and plans of Glasgow city centre.

As mentioned by Hiller and Hanson (1984, p. 29) spatial order is a result of economic activities as well as culture, climate, and society. Relation between society and space, the arrangement of people in space and the arrangement of space itself is the key in understanding how urban space is formed through time (Hillier & Hanson, 1984).

Since street networks allow the movement of people and goods, connect local to regional scale they play a central role in the spatial organisation of urban areas (Strano, et al., 2012, p. 1). And

although generally the buildings tend to change over time, the street networks more resilient to change and retain the overall geometry throughout time (Wang, 2015).

Kostof (1990, p.190) mentions that streets are one of the inventions of human with public, economic, cultural, social and political roles that connect people and places, allow social exchange and communication, enable exchange of goods and structure community. Lynch (1960) mentions the five elements of urban structure as the basics of urban form: nodes, paths, edges, districts and landmarks.

Space syntax studies concentrates on the nodes and paths as the main properties of a city. Some of the main measures of space syntax includes connectivity, integration, and choice. Connectivity is a local measure and calculates the number of nodes that are directly related to each node (Hillier & Hanson, 1984). To describe the urban space, it focuses on street networks instead of plots, parcels or buildings (Hillier & Vaughan, 2007). Space syntax uses the street segment between intersections as the basic element. Integration (1) and choice (2) are the two measures of space syntax. Integration measures a value how each node is integrated or segregated from all others. Choice indicates "how many distance-minimizing paths between every pair of segments lie on each segment under different definitions of distance" (Hillier, 2009).

As mentioned by Strano, et al., (2012) "Trying to understand the drivers of street network change/urban evolution, and elementary spatial mechanisms that govern/affect urban change/development/" will not only help to understand the existing spatial issues and patterns but also will guide the future policies and developments.

3 STUDY AREA - HISTORICAL DEVELOPMENT OF GLASGOW

Glasgow, the largest city of Scotland, is one of the 32 council areas for Scotland and includes 23 wards, covering an area of 175 km2 with a population of 606340 (www.glasgow.gov.uk). Although it was designed as a burgh of barony in the 12th Century, it started to grow significantly in the seventieth century. During the 1780s growing overseas trade created a population increase and a demand for housing. With the impact and opportunity of natural advantages (supplies and location) coal and iron mining, cotton manufacture, shipbuilding on river Clyde and overseas trade were thriven during the 18th and 19th centuries (Checkland, 1964, p. 38). In the 19th century, while the workers and the factories mainly located in the old core and the east end, the middle class moved to cleaner neighbourhoods in the west of the city (Checkland, 1964; Reed, 1993).

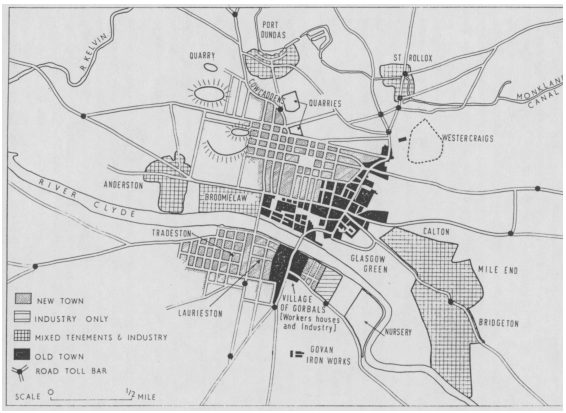

Figure 1: Glasgow in 1825

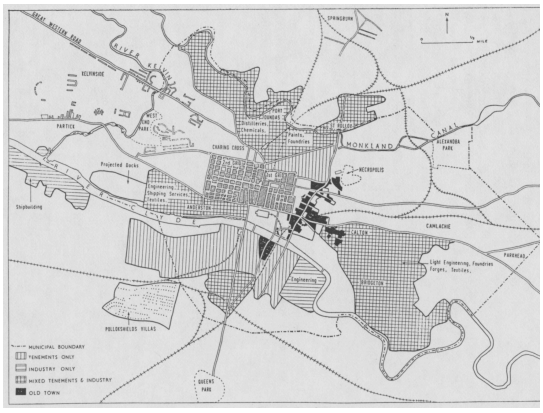

Figure 2: Glasgow in 1875

The gridiron development in the north-west of the Glasgow Cross was started to develop in 1820s for middle class housing. From 1850 to 1875 Glasgow had experienced the most dramatic development of its history, that "established the shape of the city" (Checkland, 1964, p. 46) (See Figure 1 and Figure2).

Glasgow's development was a result of economic activities, the movement of materials and movement of people in space. Rapid industrial development followed by land speculations, caused spatial separation of certain socio-economic groups in the city. High population density and traditional tenement housing were causing sanitation and public health issues. The Glasgow grid started to develop in the beginning of the 19th century to tackle with housing and sanitation problems in the city centre.

Four distinct phases could be identified in Glasgow's history, including 1) Pre-industrial phase dominated by overseas trade, 2) industrial phase defined by shipbuilding, rising manufacturing activities, pollution, high residential densities, 3) post-industrial phase: decline of industries, population loss, decentralisation by government, 4) Neo-liberal phase: economic decline and unemployment, urban redevelopment, regeneration of urban economy by tourism and service sector investments, large scale planning projects (Pacione, 1995). This study concentrates on 3 phases, industrial, post-industrial and neo-liberal phase. The following parts briefly explains each of these periods regarding the selected time intervals for axial analysis.

3.1 Industrial phase: The end of 18th and the beginning of 19th century

By the 1780's the growing overseas trade created a rise in population and a large need for dwellings. However, by 1825, most of the traders had abandoned their old homes and relocated to the west due to environmental and social decline in the city centre, and Glasgow Cross, the city's medieval centre, had become a slum area. Gorbals, and the city's centre were both suffering from air pollution caused by steam engines and heavy industry. The city centre was no longer liveable for the wealthy, who quickly relocated to new districts in the west and north-west of the old core due to pollution and deterioration (Checkland, 1964, p. 43).

From 1850s to 1875 the rapid growth established the shape of the city. The Canal remained the northern boundary for the city centre. Cowcaddens developed in 1866 had become a slum by 1875. Industries and population kept growing in Port Dundas. St Rollox also started to develop including chemical works, foundries and potteries kept growing during this period (Pacione, 1995).

By 1900 the canal was still a barrier in the north of the city centre. Springburn railway complex was growing with new investments. Due to environmental problems in the city centre the middle class had been moving towards the west and Kelvinside, and however, Sauchiehall Street was turning into shopping street for middle class.

By the 1920s Glasgow was the least suburban city compared to similar sized cities. More than a million people were living close to the heart of the city (Reed, 1993). However, through the 1930s the City Council involvement in housing development had increased and the suburban settlements were developed outside the city centre. Between 1925 and 1938 the city had doubled in size, and "the new suburban settlements were connected to the center with new boulevards and tramlines" (McKean, 1993, p. 132).

3.2 Post-Industrial phase: Glasgow between 1950s to 1980s

Industrial growth of 19th century followed by migration, population growth, and rapid urban development in and around the city centre. This upward growth trend is lasted till the mid of the 20th century and by the 1950s the industrial decline and population loss not only caused physical decline in city centre but also created social and economic problems. From 1950 to 1980s the city's population decreased from over a million to 600.000 (Urban, 2018). In order to regenerate the economy, it was aimed to develop service sector -retail, tourism, leisure- and the regeneration of urban land with high-rise tower buildings and regionally connected motorways (Urban, 2018; Collins & Levitt, 2020).

As mentioned by Collins & Levitt (2020) three major policy discourses drove Glasgow's transformation. First, from 1945 to 1960, the regional policy aimed to decentralize the population and industry out of Glasgow to encourage industrial development out of the city's vicinity and to deal with social and economic issues of inner city. Slum clearance program in 1955 (Hall, 2014) were applied and the regeneration projects were resulted with demolition of tenement houses, construction of high-rise towers and M8 motorway. Second, between 1960 and 1979, distant New Towns started to be planned for "skilled labour" which caused new social and infrastructural issues for the metropolitan Glasgow. Third, by 1979, a neo-liberal discourse started to be followed, and the population movement from Glasgow to the suburban areas continued (Collins & Levitt, 2020, p. 2). As a result of these policies between 1971-1981 Glasgow lost its population by 22% and the unemployment rose from 7.51 to 14.81 (Middleton, 1987, pp. 8-9). Urban (2018, p.265) defines the 20th century Glasgow as "a sculpture park of failed modern

utopias with Corbusian towers, La Défense style deck urbanism, megastructures, inner-city motorways, partially finished garden cities, new towns based on cluster urbanism, vast vacant areas, and closed down factories".

4 METHODOLOGY:

4.1 Study Area

As mentioned earlier this study concentrates on Glasgow city centre and the evolution of street network since the 19th century. The city centre is surrounded by River Clyde and Govan on the South, Port Dundas Canal on the North. M8 motorway cuts through the area creating a barrier between the city centre, Anderston and Port Dundas. In the scope of this study, 17 km^2 area has been selected for the analysis including the historic core of Glasgow City Centre which gathers the administrative uses, commercial and business centres.

4.2 Space Syntax

The primary idea of space syntax is that the space is represented as a network, with street intersections as nodes and street segments as edges. The spatial organization that develops from the urban network is the cornerstone of space syntax (Jguirim, et al., 2014). In this study the space syntax has been selected for analysis as we believe that it is suitable and functional to explore the evolution of street network in Glasgow. The street network has been drawn in vectorial format in AutoCAD then imported in DepthMapx8 software for each period. Following the axial analysis, the segment analysis was carried out. In this paper two kernel parameters have been used: Normalized Angular Choice (NACH) and Normalized Angular Integration (NAIN). The frequency with which the shortest topological path between two other arbitrarily chosen streets within the study scope crosses a particular street is referred to as $NACH_R$. It may be thought of as the streets' commuting capacity, or their ability to handle traffic flows (Wang, et al., 2018). The following is the definitions of the model for $NACH_R$:

$$NACHR = \frac{\log (Achoice\ R+ 1)}{\log (Atotal\ depthR+ 3)} \quad (1)$$

The near-far distance that a single street is from all other streets within the study scope is referred to as $NAIN_R$. The following is the definitions of the model:

$$NAIN_R = \frac{NC_R^{1.2}}{Atotal\ depth_R} \quad (2)$$

Table 1: Selected space syntax parameters

Name	Definition
Integration	is a normalised measure of distance from any space of origin to all others in a system. In general, it calculates how close the origin space is to all other spaces,

	and can be seen as the measure of relative asymmetry (or relative depth) "degree of the topological accessibility of a certain street compared with all other street segments"
Choice	Counting the number of times each street segment falls on the shortest path between all pairs within a selected distance (radius) Choice measures how likely an axial line or a street segment it is to be passed through on all shortest routes from all spaces to all other spaces in the entire system or within a predetermined distance (radius) from each segment.

4.3 Data collection and processing:

The historical maps used in this study were obtained from Digimap.edina.uk. Using approximately 20-40 years as the time interval it was aimed to see the change in the land use, density, urban form and street layout. Six-time nodes were chosen for different periods, including 1860, 1890, 1930, 1960, 1980 and 2021 (Figure 3). Each time node reflects the street network and urban form of this stage. Cartographic accuracy was an important criterion for the selection of historic maps. Availability of map information was also another selection of reason.

The axial maps of each period were drawn by using CAD software. Following this process, to create the topological data set, the axial maps were imported into DepthMapX8, with the segments and their connections acting as nodes and links. Finally, the street network was represented by NACH and NAIN.

We use the NACH (normalised angular choice) analysis with multiple metric radii to assess global and local choice. Higher choice (betweenness centrality) levels refer better connections from an area to other parts, lower choice levels signify spatial isolation and lower spatial accessibility. The paper establishes multiple metric radii of the space syntax to assess global and local choice of R=2000, R=1200 and R=400 m. 5 minutes walking distance of 400 m was chosen for the initial analysis and the analysis repeated multiple times 3 and 5 times. Global choice (R=2000), local choice (R=400 m) global integration and local integration are used to analyse the street network.

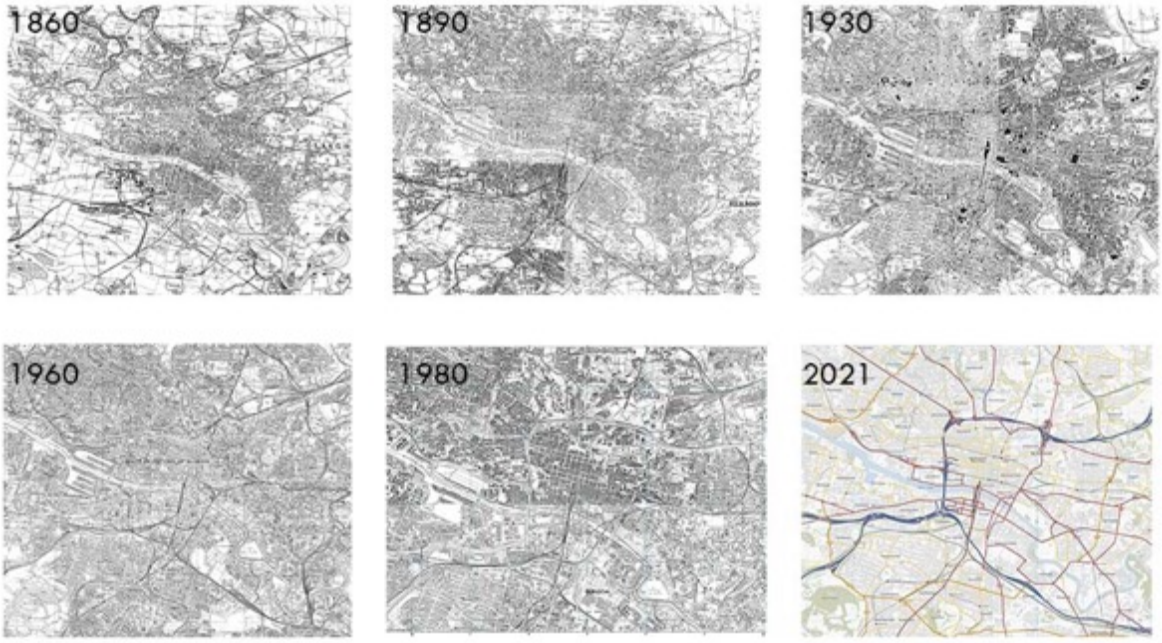

Figure 3: Maps from six different periods (1860-2021) Source: (Digimap.edina.ac.uk, 2022)

Table 2: Historical stages and the sources of the maps

Time of the map		Important historical events	Characteristics	Source
1	1860	Industrialization	Rapid growth of industries and population	Digimap.edina Historic roam
2	1890	Economic and urban growth	Engineering and shipbuilding	
3	1930	Economic Depression Second World War 1939-1945	Mass unemployment, poverty, and poor housing conditions	
4	1960	Post-war era. Decline of industries population loss. De-industrialization	Construction of M8 motorway Slum clearance program New towns Redeployment of skilled population	
5	1980	Economic crisis: Neo-liberal discourse Culture of enterprise Glasgow East Renewal Project	Regeneration, social housing, development of service sector, renovation projects Population loss continued	
6	2021	Great recession of 2008 Commonwealth games 2014 Climate change	Adaptation to climate change, regeneration projects for city centre, adaptation to spatial outcomes of Covid pandemic	Digimap Edina Ordinance survey map

Although in this study, only the city centre is included in the analysis, the results show that choice and integration values from 1860 to 2021 decreased over the years with the effects of transportation projects and street layout alterations. We hope to further analyse the global choice and integration values including the whole city to see the differences between inner and outer city in terms of commuting efficiency, regional connectivity, choice and integration values.

The analysis of the six stages shows that the accessibility and efficiency of the main streets in the city centre were superior during the early periods and were negatively affected by the construction of M8 motorway in 1965 and by the other street layout alterations after 1980s. In the

next sections, the six phases of the structural features and developmental tendencies of the street network in Glasgow city centre are further examined, with a focus on the aspects of the main streets of the city centre.

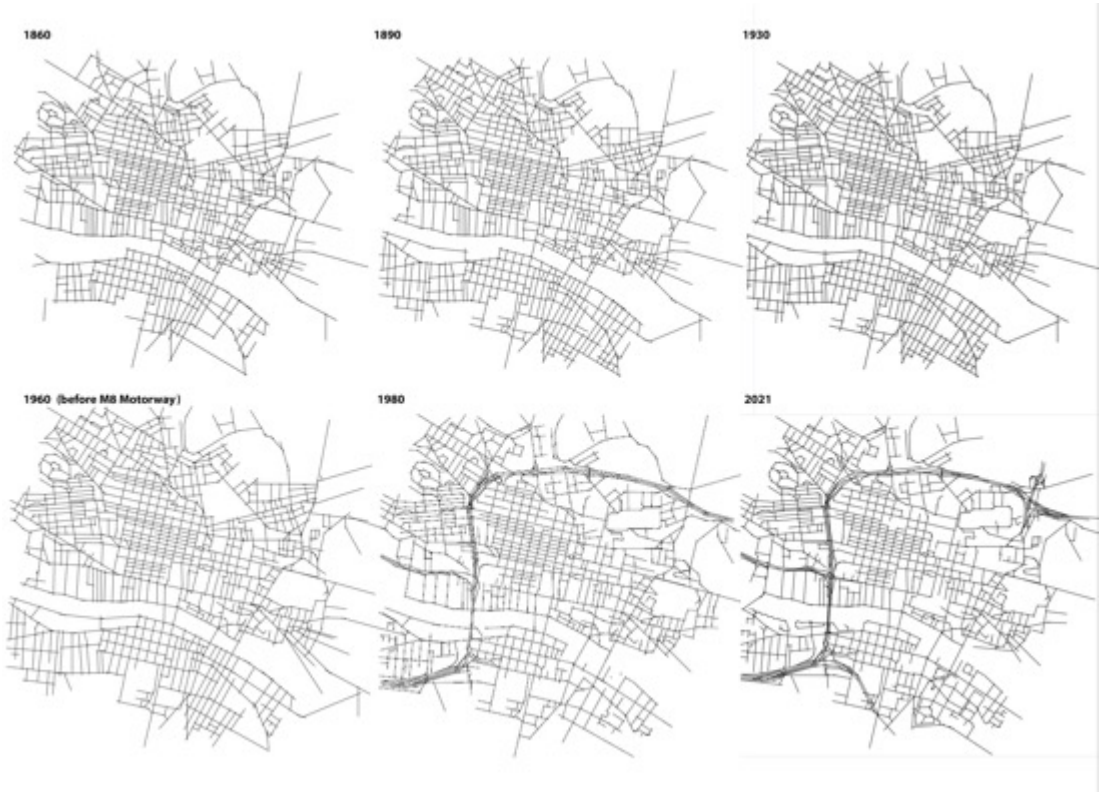

Figure 4: Axial maps for six different periods (1860-2021) Source: Authors

4.4 Glasgow between 1860 and 1960

Glasgow doubled its population and expanded its limits to include the industrial and residential burghs between 1841 and the start of the First World War. By 1850, there was a distinct divide between industry and workers' homes on the east and companies and middle-class homes on the west. The office blocks, ground floor shops, trade centres and headquarters located in the city centre. Buchanan Street, Sauchiehall Street, Argyll Street were well integrated within the network. The grid street pattern in Blythswood, located on the northwest of the Argyle Street, was started to develop in 1808 with Fleming's development plan.

Space syntax analysis for 1860 show that the 19th century city centre was globally and locally well integrated especially the north side of Argyle Street. It is also seen that the medieval part of the city including Trongate and Saltmarket streets, has a more irregular layout with shorter street segments. In addition, the south side of the Clyde River (Govan) which was developed with an orthogonal street network for the growing housing and industrial needs shows high integration and choice values providing better accessibility in the area. Overall, the network of the city centre in 1860 was globally and locally well connected. The longest paths with higher number of connections became the most important nodes for commuting as well as business and commercial

activities (Argyle, St Vincent, Buchanan, Sauchiehall Streets etc)(See Figure 5 for Integration and Choice Analysis).

Glasgow in 1890

From 1860 to 1890 Glasgow's population showed 43% growth with a migration weave (Gibb, p.124). To tackle with the issues of growing population the city developed on the south and east sides for tenement housing. The west part of the city was developed mainly as a residential area for the city's wealthier population. The historic map of 1890 provides information on the street network at that time (Figure xx).

In this period while the street structure has not changed significantly in the city centre, as the city grew towards the west and the south, the connectivity and choice values of certain streets are higher then previous period. The analysis shows that the choice and integration values for Great Western Road increased significantly from 1860 to 1890 with the new connections to the street. St Vincent Street, Argyle Street, and Sauchiehall Street with highest closeness centrality (local integration) were the most connected roads which means high accessibility and increased mobility.

The area between Sauchiehall Street and Argyle Street shows the highest integration values in the city centre with an axisymmetric grid pattern, smaller and rectangular blocks. The diagonal extension of Argyle street towards the west of the city shows a higher connectivity and choice value as it providing direct connection between west and the centre.

Glasgow in 1930 and 1960

Due to lack of historic maps between 1890 and 1930, the time gap was taken as 40 years. The global and local integration and choice values were slightly decreased in these periods. However, the integration and choice values for main streets in the city centre remained mostly unchanged between 1930 and 1960.

4.5 Glasgow between 1980 and 2021

On the global scale, in 1860 the core streets were developed, and the structure was clear. The number of tenement buildings were increasing in and around the city due to rising population and industrial activities. The city centre was fully developed and therefore the city was growing towards the outer city including south, west and east neighbourhoods. Between 1860 and 1960 the city centre retained its overall structure with higher local and global integration values. However, in 1965 the street layout was distinctively affected by the construction of M8 Motorway and significantly changed at the edges of the city centre. In addition, the redevelopment projects of 1980s and 1990s in the south side had altered the built environment

with mass demolition of buildings and created new street layout with many disconnected segments.

Integration analysis of the city centre also show that global integration and local integration values decreased after 1965 which reflects in the 1980 analysis by effects of new transportation infrastructure.

5 RESULTS

Integration analysis (segment)NAIN1200

Between 1890 and 1960's, the city centre seemed well integrated for socio-economic attraction. The North-south and West-east axes both integrate different areas to the centre. The integrated area is centrally located and serves neighbouring areas without interruption. With the motorway construction in 1965, the integration levels decrease in 1980 especially where the roads were cut through the highway. Highway linking points from east to West and North to South become new potential integrated axes.

In 2021 the integrated area loses its centrality. The most integrated areas are concentrated closer to the immediate surrounding of the highway. The highway starts to be better linked to the surroundings. However, we can not see much change in the fact that the centre and the northwest on both sides of the highway cannot be naturally linked. The integration pattern is created over the years by providing access from both sides of the highway.

Table 3: Changing tendency of the overall mean value of each period for 1860-2021

Period	Global choice (NACH 2000)	Local choice (NACH 400)	Global integration NAIN 1200	Local integration NAIN 400
1860	2.80	2.33	1.29	1.96
1890	2.81	2.35	1.24	1.98
1930	2.79	2.30	1.21	1.96
1960	2.75	2.24	1.23	1.95
1980	2.47	1.53	0.90	1.58
2021	2.41	1.51	0.85	1.47

Choice analysis (segment)NACH1200

Choice analysis explains that the highway gradually becomes an important asset for the city in terms of accessibility. In 1960, the city was well linked and almost every axis had a high choice value. These axes don't have any additional value compared to each other as they are part of a grid. This changes with the implementation of a highway, and in the 1980s, we can see some axes are poorly connected to the highway and cannot cross the highway. This means that the highway

is not well integrated to every junction in the first years, hence we see interruptions of traffic, resulting in some axes in the grid having lower choice value compared to 1960. The West and east of the highway seems to connect only with roads perpendicularly crossing the highway. We see that in 2021, the through-movement is mostly concentrated along and/or in the same direction as the highway. This means that through the years, the integration of motorway to entire system has increased further with new connections and junctions. Since it is better connected, the highway becomes a road that has a higher choice value.

The initial results show that;

- Glasgow grid-like street network has been mostly maintained over 300 years.
- Active city center remains mostly same however the land use has been transformed after the de-industrialization of the city.
- Although M8 motorway provide regional connection, it created a new barrier in the city specifically on the west and north side of the city center by cutting through historic streets namely Argyle Street, Sauchiehall Street and Great Western Road connections.

6 CONCLUSION

By conducting historical research and space syntax analysis, this paper aims to evaluate the spatio-temporal evolution of the street network in Glasgow. Although the analysis has not been finalized yet, the research that has been conducted so far shows the mechanisms effective in the transformation of road network and investigates the strong relationship between structural characteristics of network and policy decisions.

The analysis on six periods (from 1890 to 2021) indicated that the structure of the street network maintained its overall structure from 19th century to 20th century during its growth. However, the radical planning decisions and construction of M8 motorway in 1965 changed the street network dramatically, causing connection issues and physical barriers in the city center which is obviously seen in 1980 axial analysis. The results also show that the planning interventions in 1980s slightly improved the integration of M8 motorway to existing street network which is seen in the axial analysis of 2021.

With the initial results, we decided to extent the study area including the whole city. Therefore, the analysis will be repeated for 1890, 1930, 1960, 1980 and 2021. With further analysis we believe that the global choice and global integration values will be more accurate.

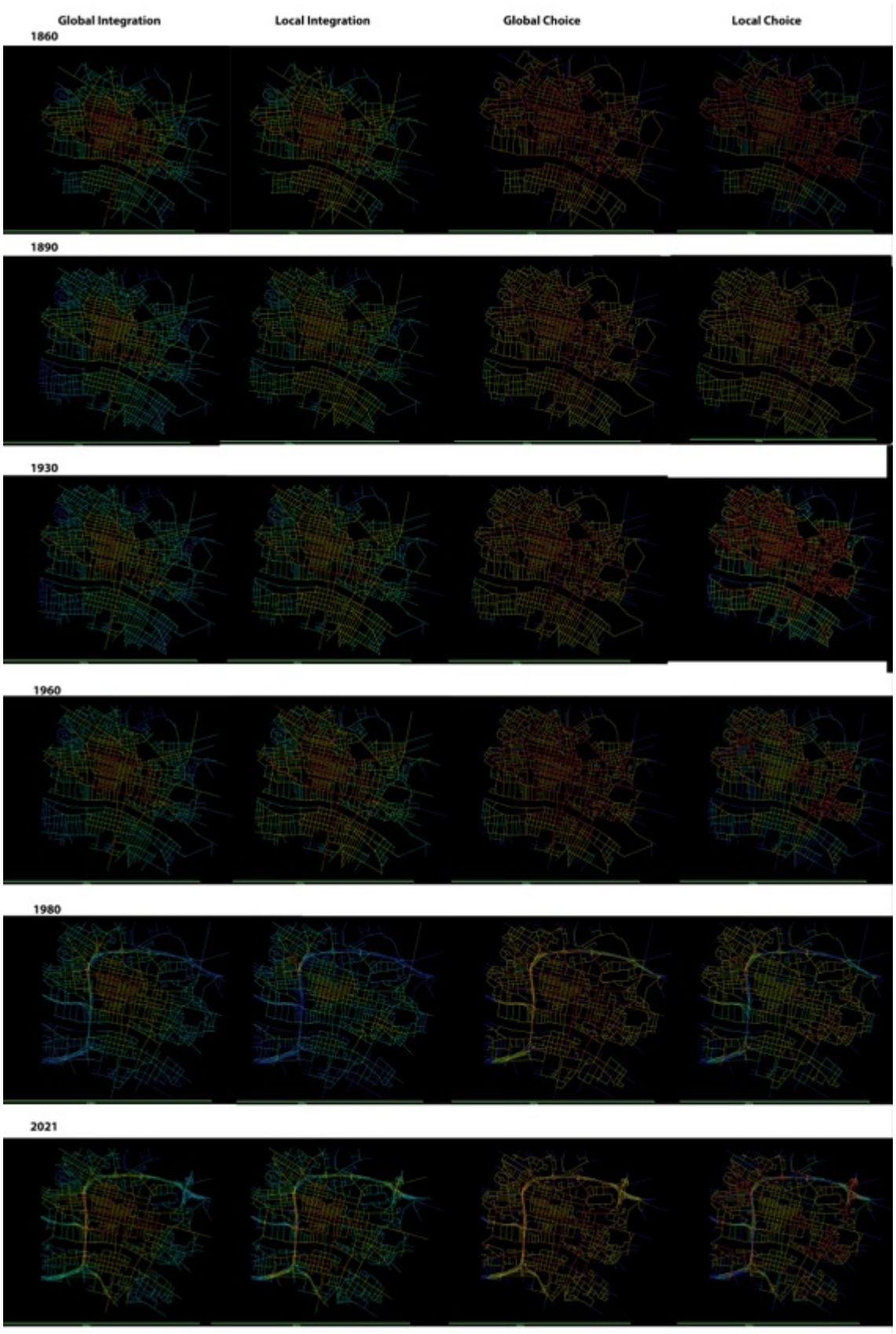

Figure 4: Connectivity and Integration analysis for 1960, 1980 and 2021 via Space Syntax and Depthmap Software

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